EELV Booster Assist Options for CEV

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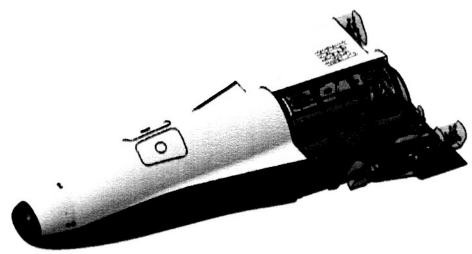
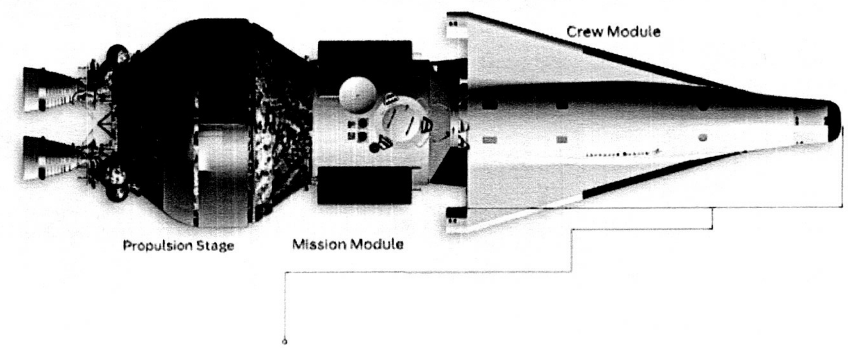
Disclaimers--first and foremost

- **I have no knowledge of the CEV proposals other than what has been publicly disclosed**
  - Thank you Popular Mechanics





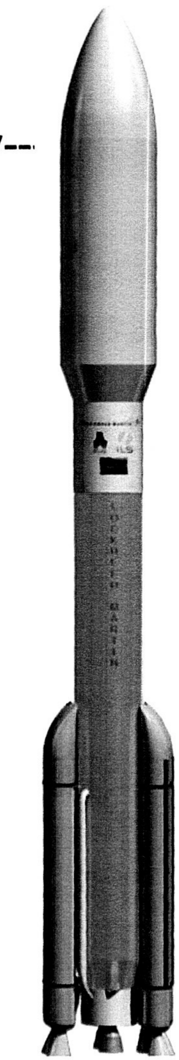
- **I can not discuss CEVs due to the procurement blackout.**
  - If I make any inadvertent comment about the relative merits of any concept, please excuse and ignore me

These are interesting and evolving times....

- **One year ago the OSP program was completing it's final study of man rating Atlas and Delta EELVs for use as OSP launch vehicles (Bulman report)**
  - Schedule driven to use existing launchers
  - Cost driven to use existing launchers
  - Modest mission requirements (ISS servicing) required modest lift capability--probably medium lift EELV

- **This year begins with CEV on a long slow exploration road**
  - 2014 Operational goal
  - Cost not an issue--spiral unfolds to meet funding profile
  - Lunar mission focus
    - ISS a secondary consideration

- **Today brings new challenges**
  - 2011 Operational goal for CEV
  - Cost is again an issue -- parallel CEV development and Shuttle operations
  - ISS service capability now a priority
    - Potentially leads to 2 CEV configurations
      - **CEV-ISS for station servicing (OSP)**
      - **CEV-E for exploration**



OSP-ELV Human Flight Certification
Study Findings & Recommendations

- "The requirement for <u>a lead time in advance of an explosion</u> is particularly troubling when SRMs are considered. Flight failures have shown that these <u>occur without warning</u> and manifest themselves as catastrophic breakup of the entire stack."
- "However, the Team noted that in <u>one of the four</u> flight SRM failure cases, video and telemetry conclusively showed that the <u>payload and upper stage emerged from the failure intact</u>."
- "A further complication from SRMs is the <u>inability to terminate thrust</u> prior to initiating a spacecraft abort. This could be significant depending on number/size of the SRMs, and particular phase of flight (e.g., max dynamic pressure may impart a sizeable drag deceleration on the spacecraft)."
- "Based on the available data and certain assumptions made by this Team, there may exist some scenarios where SRM failures in an OSP configuration <u>may be survivable</u>. However, there is insufficient data to determine that such failures will be "abortable" <u>routinely</u>."

- Recommendations:
  - R8.2–1--"The Program should continue efforts to characterize the spacecraft threats from an ELV explosion. These studies should be focused to examine the affects of full-stack explosions, with and without SRMs. Although the blast pressure environment appears to be the main threat, fragment trajectories should also be analyzed to determine whether they are a serious issue."
  - R8.2–2--"Unless the Program is able to generate new data that demonstrates that SRM explosions are "abortable," the program <u>should not plan to use</u> ELV configurations with <u>strap-on SRMs for crewed flights</u> of the spacecraft."

SRB Boost Assist for EELV

- **Atlas V Medium is designed to use 5 Aerojet SRBs**
- **Delta IV Medium is designed to use 4 Thiokol GEM60s**
- **Deletion of the boost assist motors from either launcher significantly reduces lift capacity**
  - Atlas payload reduced to 22,707lbs from 45,238lbs to LEO
  - Delta payload reduced to 20,075lbs. from 30,575lbs to LEO

Boost Assist is an enabling subsystem for use of Medium EELVs for CEV

- **Current commercial SRBs produced for Lockheed Martin and for Boeing are not man-rated**
  - Existing motors have (or had) detail design deficiencies
    - Nozzle cracks and ply separations on GEM60 motors
    - Aerojet nozzle to case joint design features un-necessary leak paths
    - Aerojet nozzle liner uses obsolete materials
    - Design margins lower than Shuttle SRBs
  - Commercial qualification tests performed to date are not adequate to establish manned flight readiness
  - Motor Case failure could potentially cause failure of the Atlas or Delta core vehicle in a catastrophic manner-- Violates two fault tolerant design requirement

Two Boost Assist Options for CEV

- **Option 1--Man-rate the EELV SRBs**
  - Redesign motor details
    - Eliminate known design deficiencies
    - Incorporate Shuttle SRB design solutions where applicable
    - Increase design margins
  - Incorporate positive protection against motor case rupture (New Design)
  - Implement Shuttle SRB level of Parts and Process Controls
  - Perform a series of qualification tests to establish readiness of redesigned motor and controlled processes and parts to support manned flight

- **Option 2--Replace EELV SRBs with a derivative of the Lockheed Martin Falcon Hybrid Core Booster**
  - Tailor the design for CEV application
    - Modify motor ports and Lox pump to achieve ideal performance
    - Incorporate booster shutdown capability for safety
    - Redesign for reliability rather than low cost
  - Implement Shuttle level of Parts and Process Controls
  - Perform a series of qualification tests to establish readiness of redesigned motor and controlled processes and parts to support manned flight

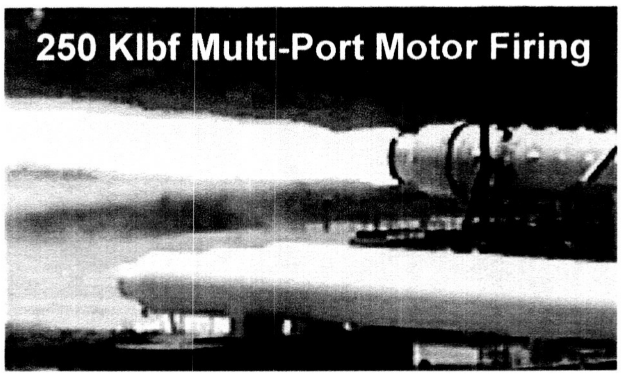
Safety Comparison of Hybrid Boost and SRBs

	Redesigned Man Rated SRBs	Hybrid Boost Assist
Manufacturing	Explosive propellant represents a threat to manufacturing personnel	Inert fuel--no threat to manufacturing personnel--Lox system checkout without fuel present
Transportation	Explosive propellant represents a threat to transportation personnel and the public	Inert fuel--no threat to transportation personnel
Launch Site Ground Handling	Explosive propellant represents a threat to ground personnel	Inert propellant--no threat to ground crews
Launch commit	Unable to shut down once started if a problem occurs	Health determination and shutdown on PAD possible
Catastrophic launch vehicle failure on the pad	Detonation of motors increases fragmentation threat to crew	Hybrid fuel only combusts under pressure--no explosive threat to crew
In Flight Abort Decision prior to Boost Assist jettison	Each booster must be explosive terminated thereby increasing fragment quantities and velocities	Shutdown of booster Lox flow results in no additional threat to crew-no explosion results

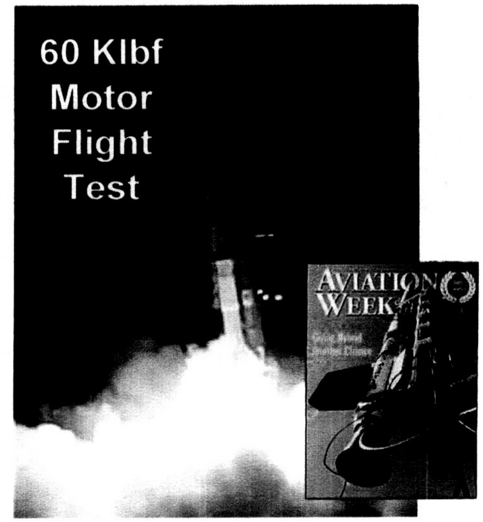
Technology Readiness Levels

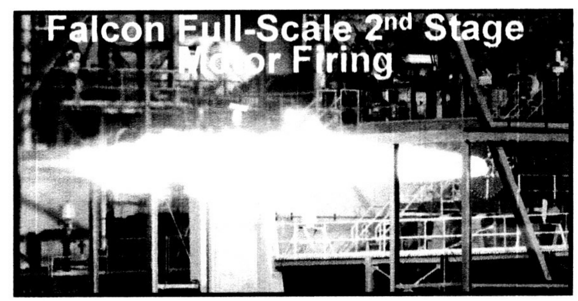
Man-Rated SRBs	TRL	Hybrid Boost Assist	TRL
Propellant	9	Fuel/Oxidizer	6
Motor case	9	Motor case	9
Nozzle	9	Nozzle	9
TVC	9	TVC	9
Igniters	9	Igniters	9
Destruct Mechanism	9	Lox Tank	9
Positive Case Rupture Protection	2	Lox Turbopump	9
		Solid Propellant GG	9
		Lox Control Valves	9
		Lox MPS Lines & Ducts	9
		Health Monitoring System	9
Integrated Motor System	2	Integrated Motor/Fluid System	4

Hybrid Propulsion Test Heritage



- **Hybrid Propulsion features**
  - **Low cost materials**
  - **Inert and non toxic fuel**
  - **Zero explosive potential**
    - Basic rubber
    - Motors cast at NASA's MAF
  - **Stop/Start and throttle capability**
    - Shutting flow of LO2 stops thrust
    - Eliminates range destruct pyrotechnics
- **Flight demonstrated hybrid propulsion in 2002**
- **Full-scale second-stage motor tested at AFRL**





16 Years of Continuous Hybrid Propulsion Development Establish The Basis For Hybrid Boost Assist

Courtesy of Lockheed Martin Michoud Operations

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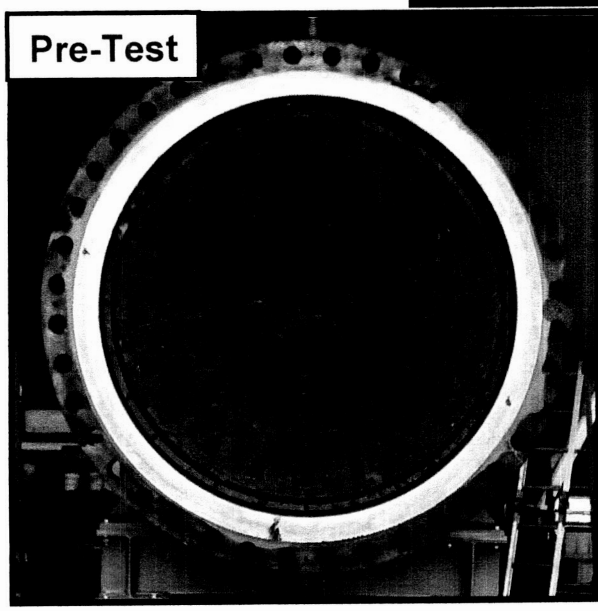
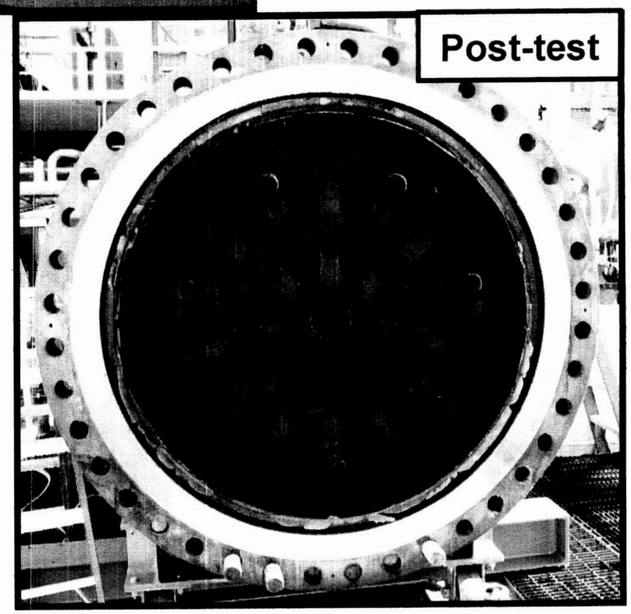
Multi-row Multi-port Fuel Grain Performed As Predicted

- **RR101 results validated the analytical baseline for multi-row, multi-port hybrid technology**
  - Stable Combustion
  - Favorable Regression
  - Thrust within Predictions
  - Isp within Predictions

•Test 4 Months after ATP
•60 Second Burn Time
•500 psi





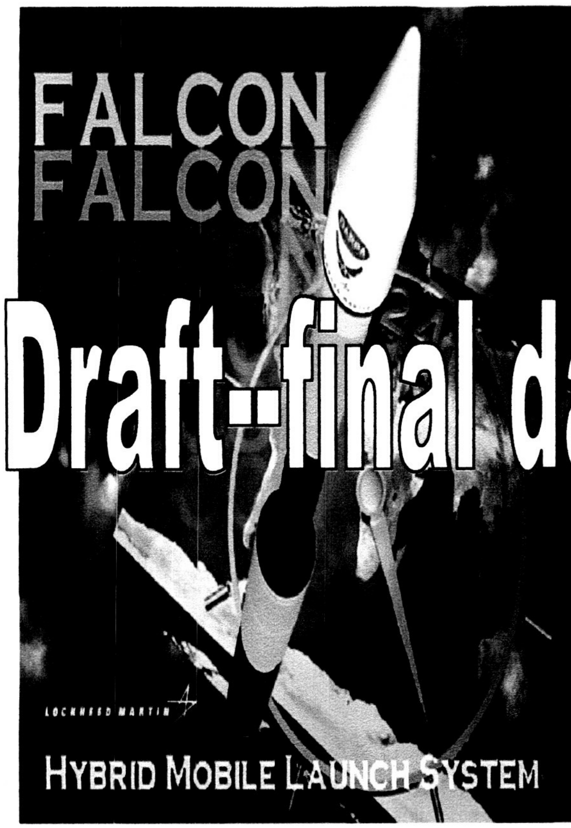
Courtesy of Lockheed Martin Michoud Operations

Man Rated SRB/Hybrid Boost Assist Comparisons

Issue	Man Rated SRBs	Hybrid Boost Assist
Reliability	SRBs have a long history of highly reliable operation due to their low parts count, lack of moving components, and careful incorporation of redundancy	Hybrid booster should have slightly lower reliability than solids due to higher parts count and moving components, but benefits from testability and health monitoring before launch.
Testability	SRB components and systems are lot tested. Flight units are not tested.	Flight Hybrid boosters can be tested during production and at the launch pad if necessary.
Development costs	Expected to exceed $35M	Expected to be less than $20M
Recurring costs	Unit cost above $4.5M	Unit costs below $3M

Performance Improvements From Derived Falcon Hybrid Booster Assist Motors and EELV Core Boosters

- Derived boosters maintain common use of Falcon tankage and motor tooling
- Hybrid Motor ports and Lox flow components resized to provide improved performance relative to SRMs



Atlas Hybrid Boost Assist System	
Weight (lbs)	147900
Burn time (sec)	97
Total Impulse (LB-SEC)	39.5M
Avg Thrust (LBT)	415000
Max [illegible](LBT)	420000
I[illegible]	[illegible]5

Delta Hybrid Boost Assist System	
Weight (lbs)	14[illegible]500
Burn time (sec)	114
Total Impulse (LB-SEC)	39.7 M
Avg Thrust (LBT)	350000
Max Thrust(LBT)	360000
ISP (sec)	315

55,000 lbs to LEO

45,000 lbs to LEO

Conclusion

- **Medium lift EELVs may still play a role in manned space flight**

- **To be considered for manned flight, Medium lift EELVs must address the short comings in their current boost assist motors**

- **Two options exist:**
  - Redesign and requalify the solid rocket motors
  - Replace SRMs with hybrid rocket motors

- **Hybrid Rocket motors are an attractive alternative**
  - They are safer than SRMs
  - The TRLs for Hybrids are higher than man-rated SRMs
  - DARPA's Lockheed Martin Small Launch Vehicle booster development substantially lowers the development risk, cost risk, and the schedule risk for developing hybrid boost assist for EELVs
  - Hybrid boosters testability offsets SRMs higher inherent reliability
  - Hybrid booster development and recurring costs are lower than SRMs
  - Performance gains are readily achieved